PROPOSED GENERATION AND COMPRESSION OF A TARGET PLASMA FOR MTF

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ABSTRACT

Magnetized target fusion (MTF), in which a magnetothermally insulated plasma is hydrodynamically compressed to fusion conditions, represents an approach to controlled fusion which avoids difficulties of both traditional inertial confinement and magnetic confinement approaches. It appears possible to compress a magnetothermally insulated plasma to fusion ignition conditions using existing, relatively inexpensive drivers, such as pulsed power devices (including explosive pulsed power). Hence, MTF may represent a means to demonstrate and study ignited plasmas with a very small capital investment. An ongoing LANL explosive pulsed power collaboration with the Russian VNIIEF Laboratory at Arzamas 16 is partly motivated by this application.

We are proposing to demonstrate the feasibility of magnetized target fusion by: 1) creating a suitable magnetized target plasma, 2) performing preliminary liner compression experiments using existing pulsed power facilities and demonstrated liner performance. The required plasma conditions vary for different drivers, but are approximately described by temperature > 50 ev, density > 10^{-6} gm/cm^3, current of several hundred kiloamperes, and dimensions of one to a few cm (giving an embedded magnetic field of about 50 KG). The initial candidate for creating the target plasma is a fiber-initiated Z-pinch. These pinches have already been created with relevant parameters, but need to be optimized for the MTF application. The target plasma would be diagnosed and optimized inside a static liner, using interferometry, spectroscopy, and other diagnostic tools to determine that density, temperature, magnetic field, and plasma purity and lifetime are in an acceptable regime for MTF.

Once the target plasma and the means for its generation have been optimized, we plan to conduct preliminary liner compression experiments aimed at demonstrating the near-adiabatic compression of the target plasma desired for MTF. Relevant liner compression experiments have been performed at Los Alamos in the Scyllac Fast Liner Program and, more recently, in the Pegasus facility and the Procyon explosive pulsed power program. In a series of liner experiments we plan to map out the dependence of temperature and neutron production as functions of the initial plasma conditions and the liner compression achieved. With the above research program, we intend to demonstrate most of the key principles involved in magnetized target fusion, and develop the experimental and theoretical tools needed to design and execute fully integrated MTF ignition experiments.

INTRODUCTION

Fusion in the laboratory (that is, controlled fusion) is a long-standing unsolved problem. For many years we have understood how to achieve fusion, but only by using an intense nuclear source of energy, definitely not in the laboratory. There have evolved two main paths for attempting to achieve fusion in the laboratory : 1) relatively static magnetic confinement of a tenuous, hot plasma (MCF), and 2) fusion ignition of a very rapidly assembled dense, hot plasma (ICF). The chief difficulty for the first path has been the occurrence of a multitude of plasma instabilities that

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disrupt confinement. The second path has suffered from the lack of a fusion driver that is at once sufficiently energetic, powerful, and intense to drive the dense fusion plasma to ignition. Nevertheless, the quest to demonstrate fusion in the laboratory has continued. What drives this quest? Are there other paths to the fusion goal?

Although fusion reaction cross sections have been measured by using accelerators, low level sources of neutrons have been produced in electrostatic confinement devices, and both accelerator and electrostatic based fusion have some applications, they lack one essential ingredient that has been implicit in the quest: a net energy gain. That is, they do not provide more fusion energy than the energy require to establish the fusion conditions. This points to the primary motivation for the quest, a fusion energy production system. Such a system is envisioned as clean (no fissile materials) and using a fuel that is virtually inexhaustible. However, there are secondary motivations. The challenge is certainly one motivation, but there are others. Fusion neutrons have a variety of potential uses: production of medical isotopes, transmutation of nuclear waste, production of fusion fuel (e.g., tritium), neutron scattering as a probe of the structure of matter, and breeding of fissile material. Also, the possibility of a low mass propulsion system for space exploration has long been an attractive prospect. Both energy and propulsion applications would benefit from neutronless fusion (e.g., deuterium and light helium), which is considered to be an important step beyond the easier deuterium and tritium (DT) fusion. However, despite the motivations and attractive potential applications, fruition will only come after fusion in the laboratory has been demonstrated on a scale far greater than has been realized so far. Our initial goal is simply to demonstrate DT fusion in a setting that can scale to net energy gain.

Both the main paths to fusion (MCF and ICF) are thermonuclear in nature. Although some non-thermonuclear paths have been explored, so far none have been shown to be viable as the basis for an energy production system. However, some thermonuclear based systems seem to have potential for energy production. Although energy production should not be the sole criterion for pursuing a fusion technology, it remains a primary one, given the impact that realization of fusion power could have. As mentioned at the outset, both MCF and ICF have encountered some difficulties in realization. One path to fusion that may avoid some of the difficulties is represented by the magnetized target fusion (MTF) concept.

Magnetized target fusion does not use magnetic fields to confine the fusion plasma, but rather to simply reduce the thermal conduction to material walls that confine the plasma. The reduced energy loss form the plasma to the walls allows a slow assembly of the magnetized fusion fuel [1]. MTF is intermediate between MCF and ICF in several aspects: operating density, size , timescale, and pressure. MTF is a relatively unexplored concept. There are two essential steps to realizing MTF: 1) creating a hot magnetized plasma and 2) subsequent compression of that plasma to fusion conditions. The subject of this paper is the first step.

GENERATION OF A TARGET PLASMA FOR MTF

There are several potential approaches for generating a target plasma for MTF. They include the Marshall gun, as in the case of the Fast Liner Program at Los Alamos [2], use of strong shocks in a magnetized plasma, as in the case of the Russian MAGO device [3], creation of a spheromak configuration that is supported by a neutral gas or material walls, and electrical discharge through a solid fiber, as in the case of the Sandia Phi-target [4]. There may be other approaches. The purpose of the work presented here is not to find the optimum approach, but rather to demonstrate a) that it is possible and b) what the properties of the target plasma are. To be useful for MTF it is

necessary that: 1) the average temperature exceed about 50ev, 2) the average magnetic field exceed about 50 KG, 3) the average density be in the range of 10^{-6} to 10^{-3} gm/cc, and 4) the lifetime be longer than that needed to compress the plasma and embedded field to fusion conditions, up to a few microseconds. Achievement of these conditions is possible only if the magnetic field significantly reduces the thermal conductivity in the target plasma the the plasma is sufficiently free of impurities. If the plasma-wall interaction creates dynamical effects this could lead to significant impurities in the plasma. In addition to the above physics demands, a practical engineering demand is that the target plasma be formed in a geometry that allows compression to fusion conditions.

We have chosen to pursue the solid fiber approach. It is planned to use an existing Z-pinch cryogenic deuterium fiber maker to place a fiber along the axis of a 2 cm radius, 2 cm long conducting can and to use the Colt capacitor bank at Los Alamos to discharge a current through it. Detailed 2-dimensional MHD computational modeling shows that a deuterium fiber-initiated Z-pinch, driven by a circuit having the characteristics of this bank could produce the desired target plasma conditions. The Colt bank stores 180 KJ at 100 Kv, and can deliver up to 2 MA with a 2.2 μs rise time. It is now operational, driving a variety of front-ends, such as the dense plasma focus (DPF). The deuterium fiber maker used for both the HDZP-1 and HDZP-2 experiments is available. Figure 1 schematically illustrates the planned configuration.

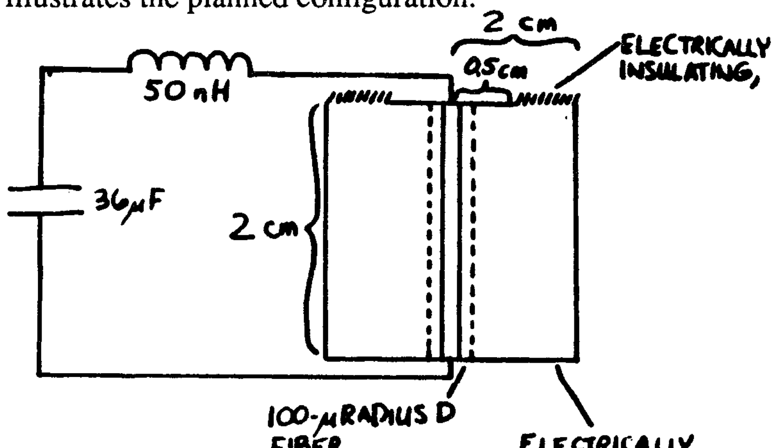

Figure 1. The proposed experiment.

In the calculations the discharge is initiated by defining a low density, hot corona around the solid deuterium fiber. The current rises linearly at first, but soon the m=0 instabilities observed in the HDZP experiments begin to grow. We have confidence in these computations because such unstable growth was predicted by this 2-D MHD code (MHRDR) before the HDZP-2 experiment was refined sufficiently to detect this pattern of growth. As the Z-pinch goes unstable it begins to expand explosively, and repeated explosive growth chaotically drives the current channel out to the wall. However, as the current approaches its peak value, the instabilities die out and the plasma becomes wall supported. This is shown in Figure 2. The 2-D plasma evolves from being very unstable to being almost one-dimensional. The average electron temperature rises to about 350 ev, but the central temperature is much higher. Also, the density is highest close to the axis, and low at the wall. The magnetic field at the wall is about 200 KG, but rises to nearly 3 MG near the axis. The profile resembles a Kadomsev stable profile. After the current begins to fall, the temperature of the plasma remains high, so that it would appear that at a suitable time the circuit can be crow-barred to chose the level of magnetic field desired for the target plasma.

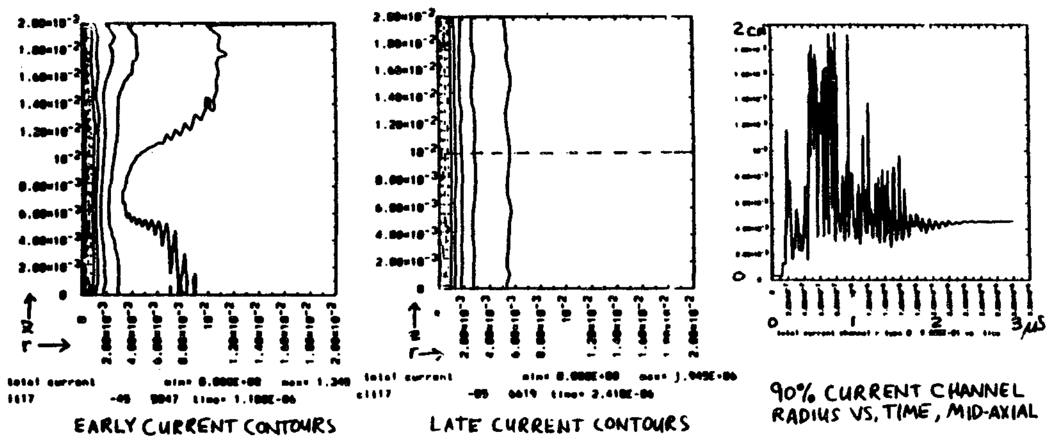

Figure 2. Establishment of wall support.

To the extent that such a plasma follows the computations reported here, it is certainly suitable as a target plasma for MTF. We are planning several diagnostics: Electrical diagnostics (e.g., "B-dot" probes) will verify the current flow through the plasma. Interferometry will measure the average plasma density along selected lines of sight. Neutron counting will provide a check on the sub-fusion conditions reached; as many as 10^{+12} DD neutrons are predicted. Radiation measurements (e.g., bolometry, spectroscopy, and filtered diodes) will provide temperature and impurity data along selected lines of sight. This should begin to address the mix issue for wall supported plasmas.

Recently, an LDRD committee at Los Alamos recommended funding for this proposed experiment. If final approvals are given for our proposal, we expect to begin putting together this experiment at the beginning of FY96. It is necessary to fabricate the plasma container, the vacuum power flow channel, and the vacuum insulator. We must then adapt the solid deuterium fiber maker to the plasma container and develop fiber-plasma initiation and plasma operation. We will then be in a position to field preliminary diagnostics, which should include the B-dot probes, plasma interferometry, bolometry, and initial neutron detection. Before the end of FY96 we hope to begin measurement of basic plasma properties. In FY97 we plan to field additional diagnostics, such as spectroscopy and filtered diodes. We plan to finish measurement of plasma density, temperature, magnetic field, and the time and space resolved impurity distribution during FY97, and we hope to demonstrate by the end of FY97 that we have a target plasma suitable for MTF. In anticipation of favorable results we will propose early in FY97 that we begin compression experiments in FY98.

CONCLUSIONS

Magnetized target fusion is an approach to controlled fusion which may avoid some of the difficulties of the traditional magnetic and inertial confinement approaches. It appears possible to investigate the critical issues of MTF at a low cost by utilizing existing pulsed power facilities. Collaborative research between Los Alamos and the All-Russian Scientific Research Institute for Experimental Physics (VNIIEF) is continuing; MTF is has been a continuing motivation for this collaboration, and the experience gained from that collaboration should be valuable in carrying out our target plasma generation experiments.

Additional research into MTF at Los Alamos, such as development of a deuterium fiber-initiated Z-pinch as an MTF target plasma will be pursued at as high a level as funding permits.

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